

IMPROVED RAILS FOR SEMICONDUCTOR WAFER CARRIERS

BACKGROUND OF THE INVENTION

1. Technical Field

[0001] This invention generally relates to vertical carriers or boats for holding semiconductor wafers during heat processing and particularly relates to carriers designed to effectively support large semiconductor wafers having nominal diameters equal to or greater than about 200 millimeters, the invention includes features for reducing crystal dislocations during processing.

1. Description of the Related Art

[0002] Semiconductor wafers, especially those made of silicon, may be conventionally processed by placing them horizontally into a holding device or carrier at intervals in the vertical direction and exposing the wafers' surfaces to high temperature gases in a furnace to form an oxide film on these surfaces or to deposit films such as nitride and polysilicon, or to anneal the wafers after ion implantation. To maximize the amount of surface area exposed to the heat treatment, the wafers are usually held in "boats," or carriers, typically comprised of parallel vertical supports, or rails, having relatively short slots evenly spaced along their length. The slots in one support are normally aligned with slots in the other supports so a corresponding slot in each support can jointly receive a wafer. By placing wafers in appropriate slots on the supports, the boat can carry a stack of wafers separated from each other so that both sides of the wafer are exposed to the heat treatment.

[0003] In the past, conventional vertical boats and carriers have been designed to support wafers having nominal diameters of 200 millimeters (mm) or less. Wafers of this size are typically supported by slots on the vertical rails that extend inward around the edge of the wafer only a

very short distance, usually less than about 20 mm. Unfortunately, when such a design is utilized to support larger wafers, i.e., wafers having a diameter greater than about 200 millimeters, the wafers are deflected by their own weight and tend to sag.

[0004] As the temperature in the furnace rises, this sagging or deformation results in crystal dislocation, or "slip," and other stresses on the wafer. Although "slip" typically begins to occur at about 1200°C for wafers having nominal diameters of 200 mm, it may occur at a temperature of 1000°C or less for wafers having diameters of 300 mm or larger. Crystal dislocations caused by stresses on the wafers result in a decrease in the number of chips that can be made on a wafer. This reduction in product yield increases with wafer size, and therefore the processing of larger wafers in conventional vertical boats has been generally avoided.

[0005] Various techniques have been suggested in an attempt to decrease the bending stress on wafers. One method suggested is to locate the rails or vertical supports of the boat or carrier more toward the front of the carrier where the wafers are loaded. This, however, is difficult because of the need for an unobstructed wafer loading path.

[0006] U.S. Pat. No. 5,931,666 discloses providing each tooth forming the slots with a rounded, downwardly sloping tip at its inner end. The rounded end reduces stress concentrations in the wafers that normally develop along the sharp edge at the end of the upper surface of each tooth in prior art designs.

[0007] Another technique for decreasing bending stress on large wafers is disclosed in U.S. Pat. No. 5,492,229, which teaches the use of relatively long support teeth, i.e., the support arms formed by long slits or slots on the support rail, with small contact pads located at or near the end of the teeth for supporting the wafers toward their center and not at their edges. According to this patent, the contact pads or support projections are located such that the inner portion of each wafer is supported by the pad while the peripheral portion, i.e., the portion of the wafer which

extends from the edge of the wafer inward a distance of up to 10% of the wafer's radius, does not contact the pads or arms. By supporting the wafers at their inner portion, this design not only reduces the stress on the wafer caused by its own weight but also decreases heat stress caused by direct heat transfer to the wafer from the slits in the vertical supports.

[0008] Although the above-discussed patent proposes the use of long support arms or teeth in order to decrease stress on the wafer, the wafer support is far from uniform as it relies on small contact pads located at or near the end of the support arms, the pads occupying only a small portion of the length of the support arm and contacting only a small area of each wafer. Moreover, the design shown in the patent results in reduced tooth strength caused by the removal of material from the top of the tooth to form the small support pads or projections.

[0009] An alternate design for carrier rails is disclosed in U.S. Pat. Nos. 6,171,400 and 6,357,604, which are both based on the same application and are incorporated herein by reference. FIG. 1 of the attached figures shows a prior-art semiconductor wafer carrier 11 that comprises a bottom portion or plate 10 on which are mounted four vertical supports or rails 12, 14. Rails 12, 14 extend upward between bottom plate 10 and a top portion or plate, which is not shown in the figures. Two rails 12 located on the left side of carrier 11 are identical and are mirror images of rails 14 located on the right side of carrier 11. FIG. 2 of the attached figures comprises perspective views illustrating the details of each side of rails 14. Generally, the design of bottom plate 10 and top plate is dependent on the type of apparatus used to move carrier 11 in and out of the furnace where the wafers are to be processed and on the design of the furnace itself.

[0010] A wafer 16 is shown in FIG. 1 as a dotted line in its appropriate position after being inserted into wafer carrier 11. Generally, the design of carrier 11 depends upon the size of wafers 16 to be held and supported. Typically, the nominal diameter of wafers 16 held in carrier 11 ranges from about 200 mm to about 400 mm, although other diameter wafers 16 can be

accommodated if desired. Wafers 16 of this size usually have a thickness that ranges from about 0.5 to about 1.5 mm.

[0011] Referring to both of FIGS. 1 and 2, each support rail 12, 14 is mounted on an upper surface 18 of plate 10, with two rails 12, 14 being located on both sides of the lateral centerline 20 and the longitudinal centerline 22. Each rail 12, 14 contains a plurality of support arms or teeth 24, 26, respectively, which in turn define slots 28 into which wafers 16 are inserted. Slots 28 are aligned so that a single wafer 16 can be jointly received by a corresponding slot in each rail 12, 14, thereby allowing carrier 11 to hold wafers 16 in a stack.

[0012] Although FIG. 1 shows four support rails 12, 14 on carrier 11, it will be understood that carrier 11 may have as few as two rails 12, 14. Although three or four support rails 12, 14 are normally preferred from a point of view of support and cost of fabrication of carrier 11, more rails 12, 14 may be used if desired.

[0013] Rails 12 are attached to and located on the left side of bottom plate 10, whereas rails 14 are located on the right side of plate 10. Ideally, for the most uniform support of wafers 16, rails 12, 14 should be equally spaced, i.e., 90°, from each other in a circle on bottom plate 10. Unfortunately, such an arrangement does not permit placement of wafers 16 into carrier 11. In order for there to be sufficient clearance to load wafers 16 into the front of carrier 11, each rail 12, 14 located on the front portion of plate 10 normally must be spaced between about 150° and about 175° from each other when measured the short way around bottom plate 10. When it is desired to utilize only three rails 12, 14 for support, two of rails 12, 14 are located toward the front of carrier 11 as shown in FIG. 1 while one rail 12, 14 is located at the back of carrier 11. Typically, rails 12, 14 in the front support between about 55% and about 90% of the weight of each wafer 16.

[0014] The '400 and '604 patents disclose a support structure or ledge 30 that runs along a side of each tooth 24, 26 from its front tip 32 toward its back edge 34, a distance equal to at least 70%, usually at least 80%, of the length of the tooth. Ledge 30 is designed to provide support for wafer 16 usually from the outer edge of wafer 16 inward to a point located from the center of wafer 16, a distance equal to between about 25% and about 80%, preferably between about 45% and 60%, of the radius of wafer 16. Although it is preferred that ledge 30 support wafer 16 from its edge inward, the actual support may begin as far as 9% of the radius of wafer 16 from the edge of wafer 16, more preferably less than 5% of the radius of wafer 16 from the edge of wafer 16.

[0015] Although ledge 30 is normally designed to provide continuous support to wafer 16 from its edge inward, it is preferable that the contact area with the underside of wafer 16 be as small as possible in order to expose the maximum amount of surface area of wafer 16 to the heat treating process and to reduce heat transfer by thermal conductivity to the bottom of wafer 16, heat transfer causing non-uniform expansion and stress on wafer 16. Of course, the actual surface area of the top of ledge 30 will depend upon the size of tooth 24, 26, which in turn depends upon the size of wafer 16 being supported. Typically, for wafer 16 having a nominal diameter between about 200 mm and 400 mm, the surface area of the top of ledge 30 will range between about 20 and 200 mm², preferably between about 30 and 120 mm².

[0016] The height of ledge 30 is normally sufficient to allow gases in the furnace to access the area between the top surface of teeth 24, 26 and the underside of each wafer 16. Typically, the height ranges between about 0.25 mm and about 2.5 mm, preferably between 0.5 mm and 1.25 mm. The distance between the top of ledge 30 and the bottom surface of the next higher adjacent tooth 24, 26 usually ranges between about 0.75 and about 4.0 mm, preferably between about 1.5 and 3.0 mm.

[0017] It has been found that, when ledge 30 supplies support to each wafer 16 beginning at a point near the edge of wafer 16 and continuing inward, stress caused by the weight of wafer 16 is

substantially reduced as compared to when support is supplied only at the inner portion of wafer 16. Moreover, utilizing ledge 30 that is integral with and occupies at least 50% of the length of each tooth 24, 26 increases the strength of each individual tooth 24, 26.

[0018] While the methods described above reduce slip during processing of the wafers, there is a need for an improved rail design for a wafer carrier. The improved design would provide a ledge that supports the wafer above the top surface of each tooth, with each ledge having rounded edges for further limiting slip by reducing stress concentrations.

SUMMARY OF THE INVENTION

[0019] A rail is provided for use as a support in an apparatus for holding a plurality of semiconductor wafers. The rail has a plurality of teeth arranged in a vertical column, such that the space between a top surface of one tooth and a bottom surface of the next higher adjacent tooth forms a slot for receiving a portion of a semiconductor wafer. A support structure for supporting the wafer is located on the top surface of substantially all teeth that form the bottom of a slot, the support structure having sidewalls and an upper surface spaced from the top surface. On each support structure, a radius is formed at each intersection of the sidewalls and the upper surface. The support structure extends for at least approximately 50% of the length of each tooth.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The novel features believed to be characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings.

[0021] Figure 1 is a perspective view of a lower portion of a prior-art wafer carrier having four rails.

[0022] Figure 2 is a perspective view of two prior-art rails of FIG. 1.

[0023] Figure 3 is a perspective view of a lower portion of a wafer carrier having four rails, the rails being constructed according to the present invention.

[0024] Figure 4 is a perspective view of two of the rails of FIG. 3.

DETAILED DESCRIPTION OF THE INVENTION

[0025] FIG. 3 is a perspective view of a wafer carrier of the invention, and FIG. 4 is a perspective view of one embodiment of the rails of FIG. 3. Rails 36 are direct replacements for rails 12 described above, and rails 38, which have a mirror image of rails 36, are direct replacements for rails 14.

[0026] FIG. 3 shows wafer carrier 40, which comprises bottom plate 10 and four vertical rails 36, 38. Rails 36, 38 extend upward between bottom plate 10 and a top plate (not shown). Two rails 36 located on the left side of carrier 40 are identical and are mirror images of rails 38 located on the right side of carrier 40. FIG. 4 shows the detail of rails 36.

[0027] Referring to FIGS. 3 and 4, each rail 36, 38 is formed as a plate-like structure, having a narrow width and an extended height. A plurality of support arms or teeth 42 define slots 44 into which wafers 16 are inserted. When rails 36, 38 are installed on carrier 40, slots 44 are aligned so that a single wafer 16 can be jointly received by a corresponding slot 44 in each rail 36, 38, thereby allowing carrier 40 to hold wafers 16 in a stack. A vertical support 48 depends from the lowermost tooth 42, the lower ends of vertical support 48 and vertical section 46 being adjacent upper surface 18 of bottom plate 10.

[0028] Each tooth 42 extends laterally outward from a vertical section 46, teeth 42 preferably being parallel and equally spaced from each other. Though shown as having a rectangular vertical cross-section, each tooth 42 may have a vertical cross-section having a different shape, for example, a wedge or a semi-circular shape. Likewise, though rails 36, 38 are shown as plate-like members, rails 36 can have other shapes. For example, they may have U-shaped or C-shaped cross-sections. The vertical height of rails 36, 38 is dependent upon the height of the furnace in which wafers 16 are to be treated. Typically, rails 36, 38 will vary in length between

about 0.5 and 1.5 meters, but are usually somewhere between about 0.6 and about 1.0 meter in length.

[0029] The number of slots 44 in each rail 36, 38 depends upon the number of wafers 16 to be held by carrier 40. This, in turn, depends upon the size of the furnace to be used for heat treatment and the separation desired between wafers 16 to adequately expose both the top and bottom surfaces of wafers 16 to the heat treatment. Normally, each rail 36, 38 contains between about 50 and about 240 slots. For a typical size furnace, the number of slots 44 normally ranges between about 80 and about 160.

[0030] A support structure 50 runs along a side of each tooth 42 from its front tip 52 toward its back edge 54, a distance preferably equal to at least 70%, usually at least 80%, of the length of each tooth 42. As can be seen in FIGS. 3 and 4, support structure 50 has a narrow width near back edge 54 and a relatively larger width near front lip 52.

[0031] Support structure 50 is designed to provide support for wafer 16 usually from the outer edge of wafer 16 inward to a point located from the center of wafer 16, a distance equal to between about 25% and about 80%, preferably between about 45% and 60%, of the radius of wafer 16. Although it is preferred that support structure 50 support wafer 16 from its outer edge inward, the actual support may begin inward of the outer edge of wafer 16.

[0032] For reasons described *supra*, it is preferable that the contact area with the underside of wafer 16 be as small as possible. Wafers 16 rest on upper surface 56, which is spaced from top surface 58 of each tooth. Sidewalls 60, 62, 64 extend between upper surface 56 and top surface 58, forming a substantially triangular, or wedge-shaped, support structure 50. To reduce the stress concentrations on wafer 16 during thermal processing, sidewalls 60, 62, 64 are rounded, forming a radius at the intersection of each sidewall 60, 62, 64 with upper surface 56. The radius is preferably 1 mm to 2.5 mm, though other values may also be used. The actual surface area of

the top of support structure 50 will depend upon the size of each tooth 42, which in turn depends upon the size of wafer 16 being supported. The combination of the raised support structure 50 and the radius along the intersection of upper surface 56 and sidewalls 60, 62, 64 effectively reduces slip beyond the reductions achieved when using either of the techniques alone.

[0033] The height of support structure 50 is normally sufficient to allow gases in the furnace to access the area between top surface 58 of teeth 42 and the underside of each wafer 16. Typically, the height ranges between about 0.25 mm and about 2.5 mm, preferably between 0.5 mm and 1.25 mm. The distance between upper surface 56 of support structure 50 and the bottom surface of the next higher adjacent tooth 42 usually ranges between about 0.75 mm and about 4.0 mm, preferably between about 1.5 mm and 3.0 mm.

[0034] Teeth 42 of rails 36, 38 respectively, are formed when slots 44 are cut into rails 36, 38, a process similar to that detailed in the '400 and '604 references. The shape of the teeth typically depends upon the shape of the plate-like member from which the rails are fabricated. Although teeth 42, as shown in FIGS. 3 and 4, are straight, teeth 42 may alternatively be wedge-shaped, tapering outwardly from front tip 52 toward back edge 54. Teeth 42 can also be curved, as is an arc of a circle. Generally, when the teeth are straight, they range in length between about 20% to about 80% of the radius of wafer 16, preferably between 40% and 60%. Normally, the teeth are between about 20 and 150 millimeters long, preferably 50 to 100 millimeters.

[0035] Several advantages are realized with the present invention. The rails of the invention provide raised support structures, limiting the non-uniform expansion of semiconductor wafers during heating that may increase stress and slip. In addition, the use of long teeth provides support for a large portion of the radius of the wafers, further limiting slip. Also, the use of rounded edges at the upper surface of the support structure reduces stress concentrations in this area, further reducing slip.

[0036] While the invention has been shown or described in only some of its forms, it should be apparent to those skilled in the art that it is not so limited, but is susceptible to various changes without departing from the scope of the invention.